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J.R. Graham

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**THE BOLOMETRIC LIGHT CURVE
OF A
CARBON DEFLAGRATION SUPERNOVA¹**

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ABSTRACT

The bolometric light curve of type Ia supernova is reconstructed from UBVRI photometry and integrated spectral scans. This is compared with the light curve predicted for a carbon deflagration. It is found that a satisfactory fit to the data can not be obtained because the luminosity declines too slowly. The reason is fundamental to the nature of the deflagration model. In a deflagration the radioactive ^{56}Ni is surrounded by a blanket of partially burnt material which absorbs the radioactive decay energy. Thus the resultant light curve is much slower than an energetically identical carbon detonation (which can reproduce the light curve) where the radioactive material is not concentrated in the core.

1 INTRODUCTION

Exploding white dwarfs which synthesize $\sim 1M_{\odot}$ of radioactive ^{56}Ni constitute a class of models for classical type I supernovae (SNIa) which satisfy a wide number of observational constraints. (For a discussion of the characteristics of type Ia supernovae see Elias *et al.* 1985, Uomoto and Kirshner 1985, Branch 1986, and Graham 1986).

At the heart of our understanding of SNIa is the radioactive decay model (Colgate and McKee 1969). This model has been successful in reproducing the main characteristics of SNIa light curves (Arnett 1979, Colgate Petshek and Kriese 1980, Axelrod 1980, Weaver, Axelrod, and Woosley 1980, Chevalier 1981, Shurmann 1983, Sutherland and Wheeler 1984). Carbon detonation models which convert a substantial fraction of the white dwarf mass to ^{56}Ni readily reproduce the light curves. But carbon detonations are inconsistent with spectra of SNIa. Around maximum light there is evidence for presence of intermediate Z elements such as Na, Mg, Si, and Ca (Branch 1980, Branch *et al.* 1982, 1983).

To produce these elements some partial burning of the white dwarf material must occur. Somehow reactions must be stopped before they proceed all the way to the iron group. In this respect deflagration models are to be preferred over detonations. In a deflagration the burning front propagates subsonically. Therefore, the white dwarf can expand, quenching the explosion, and leave some partially burnt material (Nomoto *et al.* 1984).

The similarity of synthetic spectra for a deflagration calculated by Nomoto *et al.* (1984) and observations is quite remarkable (Branch *et al.* 1985, Harkness 1985). This success confirms that the nucleosynthesis in the outer layers of the deflagration is correct. The relative abundances observed in SNIa spectra appear to be not significantly different from solar – with the exception of hydrogen (Branch *et al.* 1983), and so are not particularly unusual. Consequently, other models may yield equally good spectra and the carbon deflagration can not be thought of as a unique model. In fact, the isotopic nucleosynthesis of the iron group elements in deflagrations present major problems (Woosley, Axelrod, and Weaver 1984, Thielmann, Nomoto, and Yokoi, 1985). However, a more sophisticated approach to the propagation of the flame in a deflagration may save the situation (Woosley and Weaver, 1985).

A important observational constraint which can be applied comes from the shape of light curves. Light curves tell us about the deposition of radioactive energy in the ejecta, and hence the structure of the supernova. It is this path of investigation which is followed below. In Section 2, the advantages of narrow band and bolometric light curves are compared, and it is concluded that only bolometric light curves can be compared reliably with models. In Section 3, a bolometric light curve is constructed by integrating UBVRI photometry of well observed type Ia supernovae.. It is shown that this technique can give the bolometric luminosity more accurately than integrated spectral scans. Section 4 describes the calculation of light curves, and shows how to modify the analytic model of Weaver, Axelrod, and Woosley (1980) to treat deflagrations. Section 5 presents the results of comparing the data with the light curve of Nomoto, Thielemann, and Yokoi's (1984) deflagration W7. No satisfactory fit can be obtained, and this model must be

rejected. In the discussion (Section 6) the deflagration W7 is compared with Weaver, Axelrod, and Woosley's (1980) detonation Model B which does fit the light curves well, yet has an almost identical density structure. The difference in the light curves is identified as being due to more efficient γ ray deposition in the deflagration. The conclusions are summarized in Section 7.

2 OBSERVATIONAL TESTS USING LIGHT CURVES

The best constraints on SN models which light curves can provide should come from direct comparison of broad band photometry with predicted fluxes. This approach would take advantage of the extensive sets of UBV data which are available. Unfortunately there is a singular difficulty; at present there exists no straightforward way of calculating the emergent flux in some arbitrary band.

Previous authors (Weaver, Axelrod and Woosley, 1980, Chevalier, 1981, Arnett, 1982, Schurmann, 1983, Sutherland and Wheeler, 1984) have generated light curves by locating the photosphere and setting the temperature of a Planck or truncated Planck spectrum to give the required flux. Only at the earliest epoch ($t \leq 20$ days after maximum) does most of the radioactive decay energy get deposited behind the photosphere. Consequently, the location of the photosphere is only relevant at these early times.

Generating UBV light curves also suffers from another uncertainty, even if the photosphere is well defined. In order to establish the photospheric radius one must know the value of the opacity. A pre-requisite to this is a detailed knowledge of the composition, physical conditions and the effects of the velocity gradient (Karp *et al.* 1977). This constitutes a level of sophistication which has not yet been attained.

The simplest property of the SN radiation is its total luminosity. Until computational techniques can be found to convert luminosity to an in-band luminosity the most reliable observational test is by comparison with bolometric light curves. In this respect we follow Axelrod

(1980), and Weaver, Axelrod and Woosley (1980).

3 BOLOMETRIC LIGHT CURVES

The spectral energy distribution of a type I supernova for $t < 100$ can be described crudely by a thermal spectrum, with a significant deficit of flux in the UV shortward of $\sim 4000\text{\AA}$ (Branch *et al.* 1983), which peaks at optical wavelengths. Therefore, most of the radiant energy can be measured by ground based telescopes. In constructing bolometric light curves one would like to follow Kirshner (1980) and Axelrod (1980) who have integrated spectral scans to obtain the total flux. Not surprisingly data with sufficiently broad wavelength and temporal coverage is sparse, with the spectra of SN1972e being the only example of a satisfactory data set (Kirshner and Oke 1975, Kirshner *et al.* 1973 a,b). Another difficulty is that spectra are seldom of high photometric quality. This is illustrated by the large scatter of the data points in Axelrod's (1980) bolometric light curve. Here I advocate an alternate approach - determining fluxes from UBVR photometry and then integrating numerically over the wavelength range.

Filter bandwidths ($\Delta\lambda \sim 0.1\mu m$) are sufficiently broad so that these measurements average over absorption features ($\Delta\lambda \sim 0.02\mu m$) and the spacing of the filters is such that there are little or no gaps in the coverage. Thus integrating photometry should be at least as successful as integrating spectra, with the further advantage that the error in individual measurements are typically only a few percent.

Extensive and good quality UBVR photometry exists for SN1972e (Lee *et al.* 1972) and there is data of similar quality and coverage (but not I) for SN 1981b, (Buta and Turner 1983). Branch *et al.* (1983) have demonstrated the high degree of similarity of the light curves and colors of these two SN. Therefore, I will assume that these two events were identical and use this data to yield a single light curve. A simultaneous comparison of the B light curve and B-V color yield a relative color excess of $\Delta E_{B-V} = 0.07$ and an extinction corrected relative distance of

$\Delta\mu = -3.12$. If the date of B maximum of SN1981b was JD 2444670.5 and the color excess is $E_{B-V} = 0.14$ (Buta and Turner, 1983) then for SN1972e the date of B maximum must have been JD 2441448.5 and $E_{B-V} = 0.07$.

The integrated dereddened flux of SN1972e and SN1981b, shifted to the distance and phase of SN1972e (see Table 1a and 1b), are shown in Figure 1 and compared with Axelrod's integrated spectral scans which have been also dereddened with $E_{B-V} = 0.07$ (Table 1c). There is no systematic difference between the corrected fluxes for SN1972e and SN1981b at a level greater than the errors. If we ascribe 15% errors to Axelrod points on the basis of the internal scatter then there is good agreement between the two different methods for determining the total flux.

4 CALCULATION OF LIGHT CURVES

The analytic model of Weaver, Axelrod, and Woosley (1980) is used to calculate bolometric light curves. The advantage of the model over Arnett's (1982) approach is that it treats γ -ray deposition in a realistic density profile, and hence can be used even when a significant fraction of γ -rays escape from the SN. The model has been calibrated against numerical calculations, including a multi-energy-group, multi-angle γ -transport code. Between 2×10^6 s and 6×10^6 s after the explosion the accuracy of the model is excellent, reproducing the more sophisticated calculations to better than 5%. It is therefore more than adequate for comparing with present data. The model was designed to calculate light curves for detonations. Here it is modified for deflagrations.

The luminosity is given by the fraction of radioactive decay energy which is deposited and then escapes as UV, optical, or IR radiation without being degraded by adiabatic expansion. Thus the luminosity is

$$L(t) = M_{56} \dot{S}(t - \eta) f_{dep}(t - \eta) f_{esc}(t) . \quad (1)$$

M_{56} is the mass of radioactive ^{56}Ni synthesised in the explosion. $\dot{S}$ is the radioactive energy generation rate, f_{dep} is the fraction of this energy deposited, and f_{esc} the fraction of previously deposited energy that avoids adiabatic cooling and escapes to be observed. η is the mean interval between energy deposition and loss.

The functions f_{dep} and f_{esc} are dependent upon the density structure, expansion velocity, and the optical and γ -ray opacities. To a good approximation the post-explosion density profile of the white dwarf may be fit by an exponential of the form

$$\rho(m, t) = \frac{\rho_o^c}{t_0^3} e^{-\alpha F_p} , \quad (2)$$

and similarly the column density $\varphi = \int_r^\infty \rho \, dr$ by

$$\varphi(m, t) = \frac{\varphi_o}{t_0^2} e^{-\beta F_p} . \quad (3)$$

Where ρ_o^c and φ_o are the central values at 10^6 . t_0 is the time since explosion in units of 10^6 s. The values of α and β are important model parameters. For a detonation α and β are found from the definition $F_p \equiv F_\varphi \equiv m/m_{det}$, where m_{det} is the mass of detonated material.

The parameter α is important in determining f_{esc} because the diffusion time scale for the SN is sensitive to α . The diffusion time scale for a deflagration is the same as that of a detonation with the same density profile and kinetic energy. Thus we define an equivalent mass of detonated material m_{det}^* for the deflagration

$$m_{det}^* = \frac{E}{q} , \quad (4)$$

where E is the energy liberated by the deflagration, and q is the energy released per gram of fuel burn in a detonation [$1.51 \times 10^{51} \text{ erg}/M_\odot$ for $2(^{12}\text{C} + ^{16}\text{O}) \rightarrow ^{56}\text{Ni}$]. It follows that

if we define $F_p \equiv m/m_{det}^*$ than we can calculate the diffusion time scale of the energetically equivalent detonation and hence f_{esc} for a deflagration using the formalism of Weaver, Axelrod, and Woosley (1980).

Just as the definition of F_p is relevant to f_{esc} , F_p must be redefined to find f_{dep} . Weaver, Axelrod, and Woosley (1980) assume that the fractional γ deposition takes the form

$$f_{dep}^\gamma(m, t) = 1 - e^{-\varphi \kappa_\gamma} . \quad (5)$$

Total deposition is found by integrating over the radioactive core, i.e. up to $m = M_{56}$

$$f_{dep}^\gamma(t) = 1 - \int_0^1 \exp\left(-\frac{\tau_0 e^{-\beta F_p}}{t_6^2}\right) dF_p , \quad (6)$$

Where $\tau_0 = \kappa_\gamma \varphi_0$. Hence the correct definition is $F_p \equiv m/M_{56}$.

The composition of the deflagration differs from that of the detonation. However, this should not change κ_γ significantly. The deposition of γ ray energy is mainly by incoherent electron scattering (Axelrod 1980). For typical γ rays with an energy of 1MeV the Klein-Nishina cross-section is $2.5 \times 10^{-25} \text{cm}^2$, and so for pure ^{56}Fe , which would be appropriate for a detonation $\kappa_\gamma = 0.059 \text{cm}^2 \text{g}^{-1}$ (c.f. $\kappa_\gamma = 0.07 \text{cm}^2 \text{g}^{-1}$ recommended by Weaver, Axelrod, and Woosley, 1980). Similarly in the partially burn outer layers of a deflagration, which consists mainly of $Z = N$ elements such as ^{28}Si , $\kappa_\gamma = 0.063 \text{cm}^2 \text{g}^{-1}$. Thus composition differences are not important.

The density profile of W7 can be described by (Nomoto, private communication 1985)

$$\rho = 2.04 \times 10^{-12} \frac{e^{-3.25m}}{t_6^3} \text{ g cm}^{-3} , \quad (7)$$

and integrated to yield

$$\varphi = 656 \frac{e^{-2.92m}}{t_6^2} \text{ g cm}^{-2} . \quad (8)$$

The parameters for W7 required to calculate the light curve are listed in Table 2.

5 RESULTS

The epoch of maximum luminosity for the light curve presented in Section 3, is not known. However, the date of maximum at B is known. By adopting a rise time to B maximum of 15 days (Barbon *et al.* 1973, Pskovskii, 1977) it is possible to align the theoretical and observational light curves. This leaves two free parameters; the optical opacity and the distance to SN1972e. The opacity probably lies somewhere in the range $0.01 - 0.3 \text{ cm}^2 \text{ g}^{-1}$. Fortunately, the observations are sufficiently long after maximum that the exact value of the opacity is not crucial. In the figures a value of $\kappa = 0.3 \text{ cm}^2 \text{ g}^{-1}$ is used as this value gives an acceptable rise time to bolometric maximum.

The calculated light curve for W7 is shown in Figure 2 compared with the bolometric light curve. The distance (4.5 Mpc) has been found by minimizing χ^2 . The statistical analysis also demonstrates that variation of κ in the range quoted above has no significant effect on the goodness of fit. For Figure 2, $\chi^2 = 257$ ($\nu = 27$ degrees of freedom) and the fit is clearly unacceptable. For comparison the data set is compared with the light curve calculated for Weaver, Axelrod, and Woosley's (1980) Model A detonation (Figure 3) $\chi^2 = 32$ ($\nu = 27$) and the fit is excellent.

6 DISCUSSION

The shape of the light curve calculated for W7 is quite unlike the observations. It is clear that if this calculation is correct then W7 can be ruled out as an appropriate SNIa model. The profound difference between the detonation and the deflagration light curves is explained as follows. The density structure and energy of W7 and the detonation Model B of Weaver, Axelrod, and Woosley (1980) are very similar, yet Model B gives a good fit to the bolometric

light curve. The significant difference between Model B and W7 is the distribution of radioactive material. In the deflagration ^{56}Ni extends out to $m \sim 0.6M_{\odot}$ where as in the detonation there is radioactive material out to the highest of mass coordinates at $m = 1.35M_{\odot}$. Thus on average a γ -ray emitted with the ^{56}Ni zone in Model B has to traverse less material to escape than in W7. The effect on the light curve can be seen as follows.

At maximum light $f_{dep} \approx 1$, and eq.(1) simplifies to give the luminosity of maximum

$$L_{max} \approx M_{56} \dot{S} (t_{max}) , \quad (9)$$

(cf. Arnett, 1982). As the SN expands the diffusion time becomes negligible, and f_{dep}^{γ} falls below unity. For $t > 2 \times 10^6 s$

$$L \approx M_{56} \dot{S} (t) f_{dep}^{\gamma}(t) , \quad (10)$$

and when the optical depth to γ 's through the ejecta has become small at $t > 7 \times 10^6 s$ the deposition integral (equation 6) reduces to

$$f_{dep}^{\gamma}(t) \approx \frac{\tau}{\beta} (1 - e^{-\beta}) , \quad (11)$$

with $\tau = \tau_0 t_0^{-2}$. At late times (i.e., $t > 7 \times 10^6 s$) the ratio of luminosity at some time t normalized to the luminosity at maximum for a detonation and deflagration with the same density structure is

$$\frac{[L_{max}/L(t)]_{det}}{[L_{max}/L(t)]_{def}} \approx \frac{\beta_{det}}{\beta_{def}} \left[\frac{1 - e^{-\beta_{def}}}{1 - e^{-\beta_{det}}} \right] . \quad (12)$$

For a detonation and deflagration yielding $1.4 M_{\odot}$ and $0.6 M_{\odot}$ of ^{56}Ni respectively this ratio is ≈ 2 , indicating that the light curve of the detonation decays twice as fast as the deflagration.

If simple scaling arguments are used to calculate the light curve for the more energetic deflagration W8 ($M_{56} = 0.65 M_{\odot}$) an improved fit is obtained yet it is still very unsatisfactory.

If a deflagration is to reproduce the bolometric light curve then the flame must propagate so quickly (*i.e.* almost at the sound speed) that the end result is essentially indistinguishable from a detonation. Thus in achieving satisfactory agreement with the light curve one destroys the fit to the spectra which initially recommended the model.

7 CONCLUSIONS

The deflagration model W7 cannot reproduce the observed bolometric light curve. The reason that W7 fails where a detonation is successful is that γ deposition at late times is more efficient in the deflagration. In deflagration W7 γ 's are emitted at $m < 0.6M_{\odot}$ and so the mean deposition efficiency is higher than in a detonation where radioactive material extends nearly all the way to the surface.

Explosions with energetics similar to W7 or Model A can only reproduce the observed light curve if ^{56}Ni extends nearly all the way to the surface. This happens naturally in a detonation. However, some mixing process would have to be invoked in the deflagration to achieve this (*c.f.* the mixing of the partially burnt material required to fit the optical spectrum, Branch *et al.* 1985). Spectra do not seem to indicate that a large mass of radioactive material has been mixed up to the surface. Thus neither deflagrations nor detonations can simultaneously satisfy the joint observational constraints imposed by light curves and spectra.

To satisfy spectral constraints the radioactive material must be shrouded from view by a few tenths of a solar mass of elements such as Si, Mg and Ca. The resultant light curve will then only bear some resemblance to observations then if the ejected mass is less than $1.4 M_{\odot}$ say $\sim 0.7M_{\odot}$. A model such as that of Colgate, Petshek and Kriese (1980) or Canal Isern and Labay (1982) which invokes white dwarf collapse might yield these conditions.

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Table 1a

Bolometric Flux of SN 1972e

Time¹ (10⁶s) Flux^{2,3} (10⁻⁹erg s⁻¹ cm⁻²)

0.88	5.30
1.05	4.55
1.23	3.93
1.31	3.74
2.61	2.15
3.13	1.44
3.21	1.55
3.82	1.08
4.38	0.90

¹ Time from date of maximum light at B on JD 2441448.5.² Dereddened with $E_{B-V} = 0.07$ ³ Estimated statistical error on all points = 6%

Table 1b

Bolometric Flux of SN 1981b

Time ¹ ($10^6 s$)	Flux ^{2,3} ($10^{-9} erg s^{-1} cm^{-2}$)
0.99	5.08
1.24	3.99
1.41	3.60
1.58	3.15
1.84	2.75
2.26	2.42

¹ Time from maximum light at B on JD 2444670.5.² Dereddened with $E_{B-V} = 0.14$ and shifted to the distance of SN1972e.³ Estimated statistical error on all points is 7%

Table 1c

Integrated spectral scans of SN 1972e (Axelrod 1980).

Time ¹ (10 ⁶ s)	Flux ^{2,3} (10 ⁻⁹ erg s ⁻¹ cm ⁻²)
0.39	6.39
0.48	7.89
0.56	8.46
0.82	5.63
0.99	4.01
1.08	3.46
1.77	2.69
2.03	2.95
2.29	2.31
3.07	1.25
3.84	0.82
4.80	0.89
5.05	0.72
6.96	0.38

¹ Time from maximum light at B on JD 2441448.5.² Dereddened with $E_{B-V} = 0.07$.³ Estimated statistical error on all points is 15%

Table 2

W7 Model Parameters

M_{se}	E_k	α	β	ρ_o^c	φ_o	V_1
$(M_{\odot})$	(10^{51} erg)			$(10^{-12} \text{ g cm}^{-3})$	(g cm^{-2})	(10^9 cm s^{-1})
0.58	1.30	3.87	1.69	2.04	656	1.26

REFERENCES

- Arnett, W.D. 1979, *Ap. J. (Letters)*, **230**, L37.
- Arnett, W.D. 1982, *Ap. J.*, **253**, 785.
- Axelrod, T.S. 1980, *P.h.D. Thesis*, UCRL 52994, University of California.
- Barbon, R., Ciatti, F. and Rosino, L. 1973, *Astr. Ap.*, **25**, 24.
- Branch, D. 1986, *Ap. J. (Letters)*, **301**, L51.
- Branch, D. 1980, *Proc. Texas Workshop on Type I Supernovae*, ed. J.C. Wheeler, (Austin, University of Texas), p.66.
- Branch, D., Buta, R.J., Falk, S.W., McCall, M.L., Sutherland, P.G., Nomoto, A., Wheeler, J.C., and Wills, B.J. 1982, *Ap. J.*, **252**, L61.
- Branch, D., McCall, C.H., Sutherland, P.G., Nomoto, A., Wheeler, P.C., and Wills, B.J. 1983, *Ap. J.*, **270**, 123.
- Branch, D., Doggett, J.B., Nomoto, K., and Theilemann, F.K. 1985, *Ap. J.*, **294**, 619.
- Buta, R. J., and Turner, A. 1983, *Pub. A. S. P.*, **95**, 72, .
- Canal, R., Isern, J., and Labay, J. 1982, *Nature*, **296**, 225.
- Chevalier, R.A. 1981, *Ap. J.*, **246**, 267.
- Colgate S. A. and McKee C. 1969, *Ap. J.*, **157**, 623.
- Colgate S. A., Petschek, A. G., and Kriese, J. J. 1980 *Ap. J. (Letters)*, **237**, L81.
- Elias, J. H., Matthews, K., Neugebauer, G., and Persson, S. W. 1985, *Ap. J.*, **296**, 379.
- Graham, J.R. 1986, *Mon. Not. R. astr. Soc.*, **220**, 27p.
- Harkness, R. 1985, *Supernovae As Distance Indicators*, ed. N. Bartel (Springer-Verlag, Berlin), p183.
- Karp, A. H., Lasher, G., Chan, K. L., and Salpeter, E. E. 1977, *Ap. J.*, **214**, 161.
- Kirshner, R. P. 1980, *Proc. Texas Workshop on Type I Supernovae*, J. C. Wheeler, (Austin,

University of Texas), p13.

Kirshner, R. P., Oke, J. B., Penston, M., and Searle, L. 1973a, *Ap. J.*, **185**, 303.

Kirshner, R. P., Willner, S. P., Becklin, E. E., Neugebauer, G., and Oke, J. B. 1973b, *Ap. J. (Letters)*, **180**, L97.

Kirshner, R. P., and Oke, J. B. 1975, *Ap. J.*, **200**, 574.

Lee, T. A., Wamsteker, W., Wisniewski, W. Z., and Wdowiak, T. J. 1972, *Ap. J. (Letters)*, **177**, L59.

Nomoto, K., Theilmann, F. K., and Yokoi, K. 1984, *Ap. J.*, **286**, 644.

Pskovskii, Yu. P. 1977, *Soviet Astr.*, **21(b)**, 675.

Schurmann, S. R. 1983, *Ap. J.*, **267**, 779.

Sutherland, P. G., and Wheeler, J. C. 1984, *Ap. J.*, **280**, 282.

Theilemann, F. K., Nomoto, K., and Yokoi, K. 1985, *Astr. Ap.*, in press.

Uomoto, A., and Kirshner, R. P. 1985, *Astr. Ap. (Letters)*, **149**, L7.

Weaver, T. A., Axelrod, T. S., and Woosley, S. E. 1980, *Proc. Texas Workshop on Type I Supernovae*, ed. J.C. Wheeler, (Austin, University of Texas), p113.

Woosley, S. E., Axelrod, T. S., and Weaver, T. A. 1984, *Proc. Erice Conference on Stellar Nucleosynthesis*, ed. C. Chiosi and A. Renzini, (D. Reidel: Dordrecht) p 263.

Woosley, S. E., and Weaver, T. A., pre-print, (1985).

FIGURE CAPTIONS

Figure 1

The reconstructed bolometric flux light curve for a type Ia supernova at the distance of SN1972e. Time is measured from maximum light at B . The points are coded as follows. $\square$; integrated spectral scans of SN1972e (Axelrod 1980), $\bullet$; integrated photometry for SN1972e, $\triangle$; integrated photometry for SN1981b.

Figure 2

The bolometric light curve calculated for the deflagration model W7 compared with the combined data from SN1972e and SN1981b. The data points are coded as in Figure 1. The distance to SN1972e is 4.5 Mpc and $\chi^2 = 257$ ($\nu = 27$).

Figure 3

The Bolometric light curve calculated for the detonation model A compared with the combined data from SN1972e and SN1981b. The points are coded as in Figure 1. The distance to SN1972e is 4.0 Mpc and $\chi^2 = 32$ ($\nu = 27$).

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XBL 868-3084

Fig. 1

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Fig. 2

Fig. 3

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